Genetically derived filter circuits using preferred value components

CONFERENCE PAPER · NOVEMBER 1994

GENETICALLY DERIVED FILTER CIRCUITS USING PREFERRED VALUE COMPONENTS

D.H. Horrocks and Y.M.A. Khalifa

Introduction

In the realisation of discrete-component analogue electronic circuits it is common practice, because of costs, to specify passive component values from a set preferred of values. For the design of Integrated Circuits it can also be desirable to use a standard set of passive component values. For example, to obtain accurate ratio matching of integrated resistors and capacitors by stacking identical unit valued components [1].

The usual design approaches produce circuits in which the permitted component values are assumed to be unrestricted. The circuit is then converted to a practical circuit by simple rounding of the exact component values to the nearest value in the permitted set. Of course, in general the circuit performance realised will differ from the ideal. It may then be necessary to repeat the design with a more stringent specification or to use a more closely spaced set of permitted values, both of which can have cost implications. However if other combinations of permitted values are considered, a better circuit performance may potentially be achieved than that obtained by simple rounding. The difficulty is that in all but trivially simple circuits the space of all feasible combinations to be searched is huge.

In [2] we have shown that Genetic Algorithms (GAs) can be used to search this space. There the application is to a simple second order active filter specified by its transfer function parameters. The aim of the present contribution is to show that GAs can be successfully applied to more complex filter structures. Moreover the optimal search is carried out directly on the frequency-response template specification rather than on a specified approximating ideal transfer function, thereby avoiding this additional source of approximation.

The next section outlines the basic GA and its implementation for the present application. Results are then given for practical filter examples. An all-pole low pass responses is considered with template specified by a 1 dB pass band ripple with a pass band edge at 10^5 rad/sec , and stop band attention of -150 dB at a stop band edge of 10^6 rad/sec . The GA is used to generate both LC ladder structures and the more complex FDNR Active RC structures.

Genetic Algorithm

GAs are search algorithms which are based on the evolutionary improvement in populations based on selection and reproduction based on fitness that is found in nature. Detailed descriptions of GAs can be found in the literature, such as Goldberg [3] and Davis [4]. There are many proposed variants and the topic is the subject of much current research, one of the main outlets for which is the proceedings of the International Conference on Genetic Algorithms and their Applications, which has been held every two years since 1985.

A conventional basic form of GA has been found to perform well in the work reported here. The parameter values to be optimised are represented as a string of bits, called a *gene.* A *fitness* function is defined which is used to measure the goodness of each gene. An initial *population* of randomly chosen genes is created. From this a new population of genes is generated by randomly choosing pairs of genes, and based on their joint fitness

---

D.H. Horrocks and Y.M.A. Khalifa are with The Cardiff School Of Engineering, University of Wales College of Cardiff, UK.

probabilistic decisions are made to breed child genes for the new population. Breeding is performed by splitting both parent genes at two randomly chosen points and crossing over the corresponding gene sections. This is *two-point cross-over*. In addition, a *mutation* operation is randomly applied to each bit with a pre-defined probability.

In this application, the components to be varied are represented in the genes by contiguous groups of six bits to specify each component value. This allows components to be selected by the GA from a range of sixty-four permitted values. This range is narrower than the range of preferred values commonly used for discrete components, which span many decades, and assumed in the examples studied here. However this was not a restriction since in practice the solutions obtained were bunched and suitable initial range scaling was easily chosen to centre the component values produced within a sixty-four valued range.

The fitness function is defined from the amplitude response error. The error is calculated for a given set of component values as the sum squared excess error at frequencies where the amplitude response in dB falls outside the template. For this a linear grid of one hundred frequencies is chosen in the pass band together with the frequency of the stop band edge. Errors in the pass band are given twice the weighting of errors at the stop band edge. Different weights can be chosen but the values are not critical since with this error definition all circuits that satisfy the template have zero error. The fitness is then defined as the reciprocal of the error value, except if the error is zero in which case a large positive value is given for the fitness.

A population size of fifty and a mutation rate of eight percent gave satisfactory performance. With these control parameters the population was usually found to have stabilised by fifty generations

Results

For the response template defined above, circuits where designed by the GA approach and for comparison, also by the conventional design approach. In this investigation resistor and capacitors were chosen from the Twelve-series of preferred values, 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82, 100, ... and the Three-series, 10, 22, 47, 100, ... was used for the inductors.

In the conventional approach for LC design (see for example [5]), the lowest-order standard polynomial transfer function is first selected that meets the specification. The standard LC ladder structure, see Fig. 1, is then synthesised leading to exact component values. These are then rounded to the nearest preferred values. In this case, a seventh degree, 1 dB ripple, Chebychev transfer function is required. The component values for an assumed equally terminated 100 Ω structure are given in Table 1, And the resulting responses are shown in figure 4 (a). It is seen that the practical response no longer meets the template specification. When the GA is applied a population of designs is produced. The three fittest circuits have responses shown in Fig. 4 (b), and the component values for the best of these (series 3) are given in Table 1. For this example the template is satisfied by two of the solutions, and nearly satisfied by the third. Other examples we have tried have also been successful, but not always so. If the original specification is barely met by an exact design, or if the density of preferred values in the range is low then it is more likely that no solution exists. Even so, it is interesting that solutions can frequently be obtained with quite low component value densities as in this example where inductors are chosen from a series with only three values per decade.

This specification was also used to design an FDNR active RC circuit. This frequently used method of active realisation is well described in the literature (for example [6]). It uses Bruton's transformation on an LC prototype. The resulting circuit, see Fig. 2, requires Frequency Dependent Negative Resistors. Here these are assumed to be realised by the Generalised Impedance Converter circuit shown Fig. 3. The full circuit now has many more components than the LC case. Thus the search space is much greater, with a correspondingly greater likelihood of obtaining solutions that are better than in the LC case. This is confirmed by the responses of the three best GA solutions which are shown in Fig. 4 (c), which are now well within the 1 dB passband ripple specified. The component values for the best FDNR circuit (series 1) is shown in Table 2.

It is interesting to observe, see Table 1, that the GA-derived circuit values are in general several values away from the nearest preferred value. This confirms the merit of using the GA - it is unlikely that searching combinations of simple nearest rounded up and down values will produce a global optimum.

Conclusion

We have shown that GAs can be used to design moderately complex filter circuits where the component values are restricted to a permitted set. The designs will frequently be better than those produced by the conventional approach of choosing the nearest permitted value. A feature of this approach is that in general a group of satisfactory designs is generated which can be used as the basis for further selection according to other criteria. Another feature is that single-step design can carried out directly on the specified response without the need to find a intermediate approximating polynomial transfer-function. Our work is continuing to generalise the GA approach to a wider class of structures and types of response, and also to being able to quantify the relationship between expected circuit performance and distribution of permitted component values.

References

[1] Geiger, R.L., Allen, P.E. and Strader, N.R.: VLSI Design Techniques for Analog and Digital Circuits, McGraw-Hill, New York, 1990, pp 79-82.

[2] Horrocks, D.H. and Spittle, M.C.: "Component Value Selection for Active Filters using Genetic Algorithms", Proceedings of IEE Workshop on Natural Algorithms in Signal Processing, Chelmsford UK, 14-16 November, vol. 1, pp 13/1-13/6.

[3] Goldberg, D.E.: Genetic Algorithms in Search, Optimisation, and Machine Learning, Addison-Wesley, Reading MA USA, 1989.

[4] Davis, L.D. (ed): Handbook of Genetic Algorithms, Van Nostrand Reinhold, New York, 1991.

[5] Lam, H.Y-F.: Analog and Digital Filters: Design and Realisation, Prentice-Hall, New Jersey USA, 1979.
[6] Stephenson, F.W.: RC Active Filter Design Handbook, Wiley, New York, 1885.

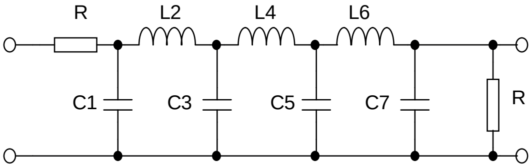


Figure 1.Low pass all-pole LC structure

	Ideal values	Nearest preferred	GA derived
R1	100 Ω	100 Ω	100 Ω
C1	0.21666 µF	0.22 µF	0.082 µF
L2	1.1115 mH	1.0 mH	1.0 mH
C3	0.30936 µF	0.33 µF	0.18 µF
L4	1.1735 mH	1.0 mH	2.2 mH
C5	0.30936 µF	0.33 µF	0.15 µF
L6	1.1115 mH	1.0 mH	2.2 mH
C7	0.21666 µF	0.22 µF	0.12 µF
R2	100 Ω	100 Ω	100 Ω

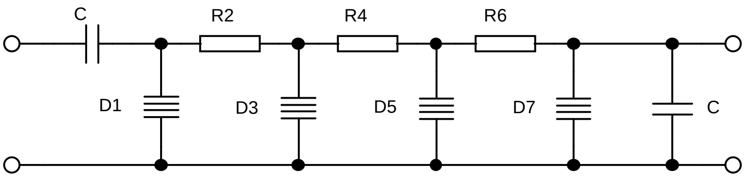


Figure 2. Low pass all-pole FDNR structure

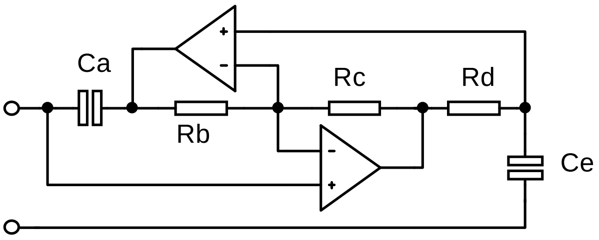
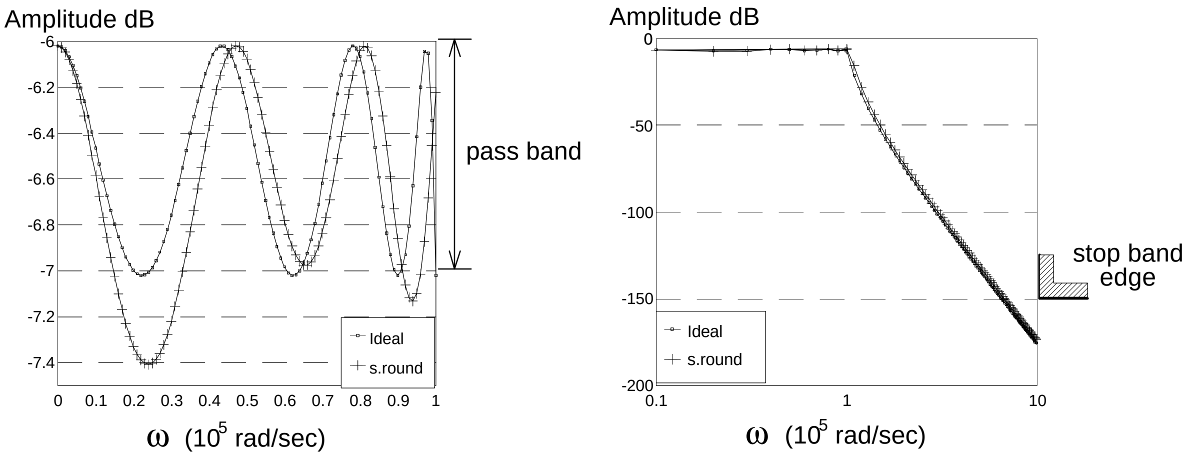


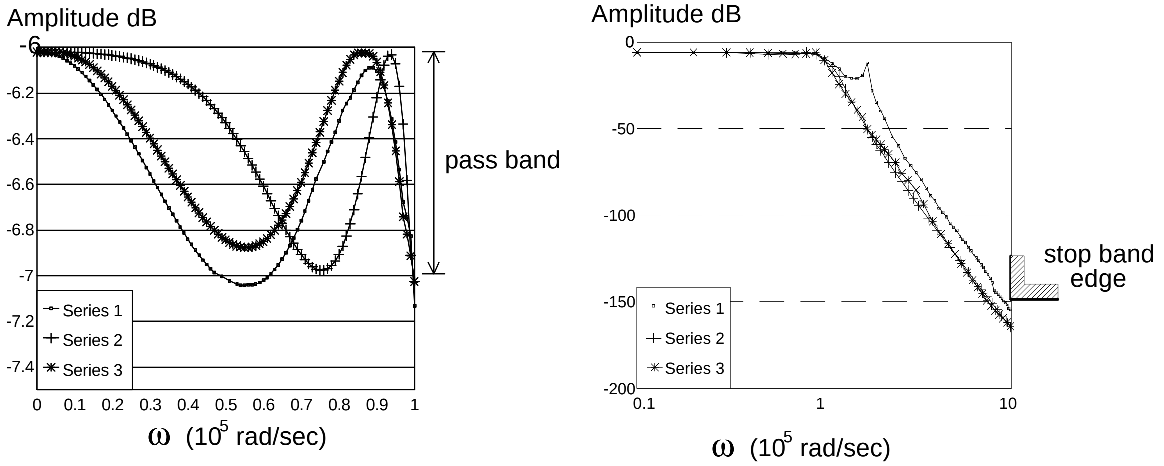
Figure 3. Generalized Impedance Convertor FDNR circuit

	Ladder values	GIC components for FDNR elements				
		Ca, μF	Rb, Ω	Rc, Ω	Rd, Ω	Ce, μF
C	0.1μF	-	-	-	-	-
D1	1.234×10^{-7}	4.7	2700	3900	3300	8.2
R2	120 Ω	-	-	-	-	-
D3	1.863×10^{-7}	6.8	1800	2700	390	0.22
R4	120 Ω	-	-	-	-	-
D5	1.771×10^{-7}	8.2	5600	1800	560	1.2
R6	120 Ω	-	-	-	-	-
D7	1.254×10^{-7}	5.6	2700	6800	820	1.0
C	0.1μF	-	-	-	-	-

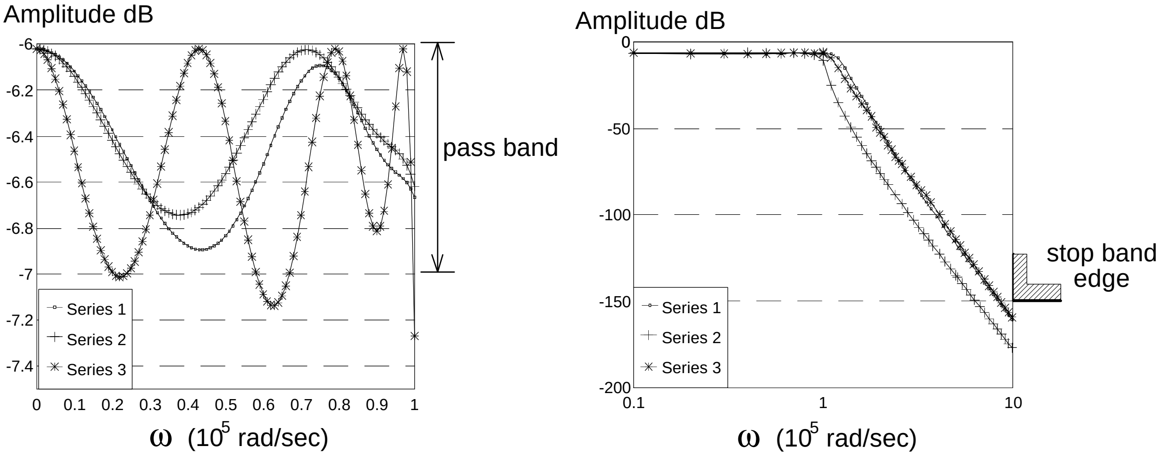
Table 2. Components for FDNR active filter



(a) Response of conventionally designed LC filter



(b) Response of GA designed LC filter



(c) Response of GA designed FDNR active filter

Figure 4. Filter responses